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ABSTRACT

This module describes the following conventional treatment systems and evaluates their use as pretreatment steps for land application: preliminary, primary, secondary, disinfection, and advanced waste treatment. Effluent qualities are summarized, a brief discussion of application systems is given, and cost comparisons are discussed in some detail. Different approaches to sizing of conventional and land application systems are discussed, and have a significant bearing on actual cost comparisons. (Author/BB)

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Land Application of Wastes

An Educational Program

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TREATMENT SYSTEMS, EFFLUENT QUALITIES, AND COSTS

Module 4

January, 1978

SE 025 018

LAND APPLICATION OF WASTES - AN EDUCATIONAL PROGRAM

The objective of this program is to increase the knowledge of engineers, scientists, waste management specialists and other practitioners in the concepts and principles needed to properly utilize the potential of land for the application of wastes. It is designed for individuals concerned with waste disposal alternatives for municipal, industrial, and agricultural wastes. The modules in this Program incorporate knowledge from sanitary and environmental engineering, agronomy, soil science, agricultural engineering, economics, and law.

The program consists of some twenty-five modules and audio-visual materials as appropriate.

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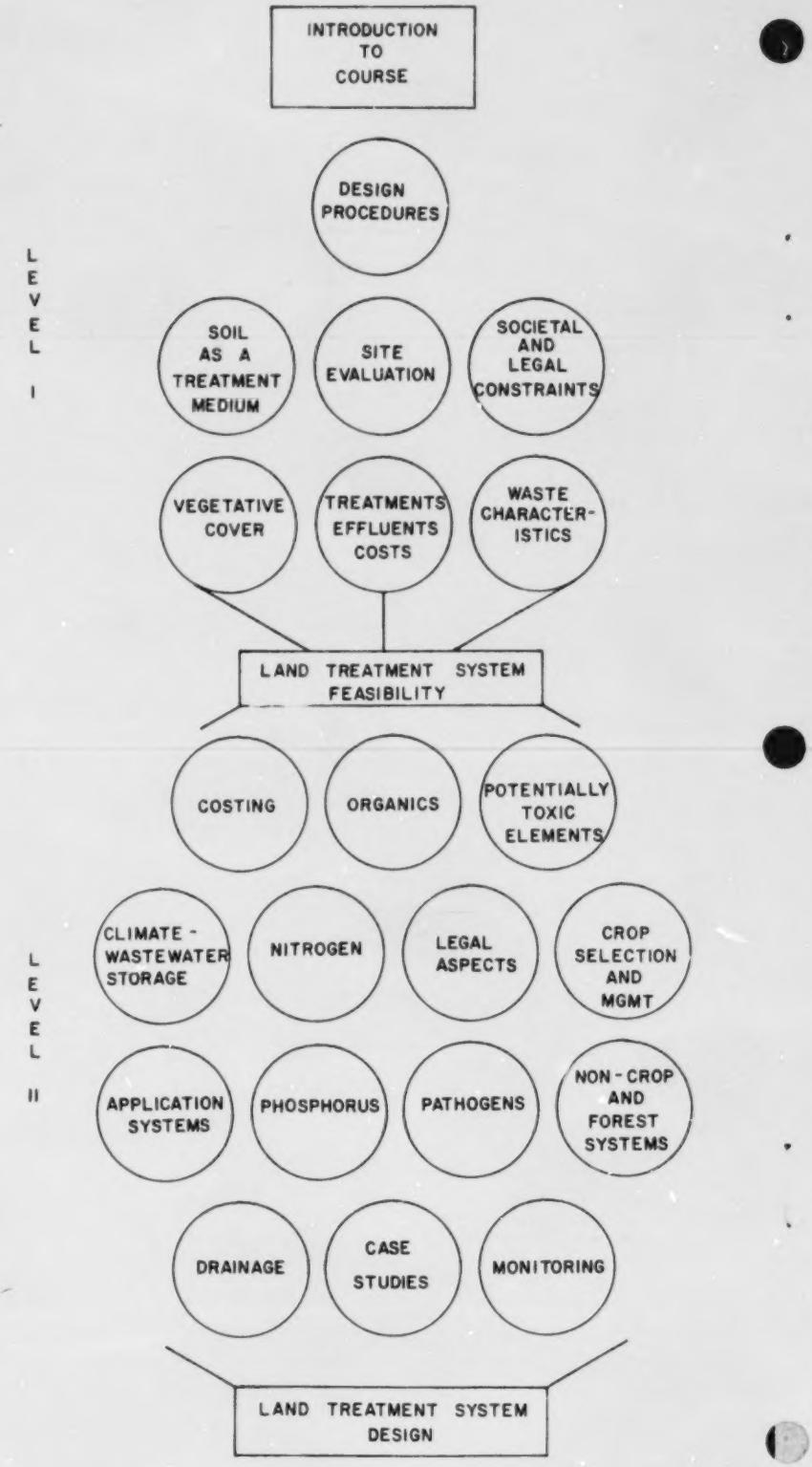

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TREATMENT SYSTEMS, EFFLUENT QUALITIES, AND COSTS

Module 4

January, 1978

Summary

Conventional wastewater treatment in some form is often used as pretreatment to land application systems. This may vary from screening to higher levels of pretreatment for some special situations. Preliminary treatment removes items which may clog subsequent waste handling equipment. Primary and secondary treatments may be required prior to moderate and high rate rapid infiltration systems respectively, in order to prevent possible soil clogging. The use of chlorine as a disinfectant prior to land application rarely is necessary, but may be required by state regulatory agencies.

Land application systems have been tailored after water distribution systems utilized in irrigated agriculture. This technology has been utilized for many years providing land application systems with an assortment of tried and proven application equipment.

In comparing conventional waste treatment to land application systems, it is apparent the latter may provide equal or better effluent qualities at lower costs. For a given situation, this can only be decided after a site specific evaluation of the treatment alternatives.

This module describes the following conventional treatment systems and evaluates their use as pretreatment steps for land application:

Treatment	Use as Pretreatment
preliminary	protection of piping and spray systems
primary	as above, plus protection of moderate rate land application from soil clogging
secondary	protection of high rate application from soil clogging
disinfection	following secondary treatment, reduction in numbers of pathogenic bacteria and viruses
advanced waste treatment	not applicable; results should be comparable to land treatment

Effluent qualities are summarized, a brief discussion of application systems is given, and cost comparisons are discussed in some detail. Different approaches to sizing of conventional and land application systems are discussed, and have a significant bearing on actual cost comparisons.

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Glossary

For the purpose of this course, the following definitions of environmental engineering terms will apply:

advanced waste treatment - Any treatment - biological, chemical or physical - which achieves removals of nutrients and/or soluble species not removed by a secondary treatment, while still attaining the suspended solids and organics removals of secondary treatment.

preliminary treatment - A subset of primary treatment. Removal of screenings and grit (readily settleable non-organic matter), without any appreciable removal of organic fraction of the wastewater.

primary treatment - Removal of screenings, grit, grease and floating solids, and readily settleable organic solids from wastewater. Treatment standards usually associate removals of about 50 to 60% suspended solids and 25-40% BOD with primary treatment.

secondary treatment - The application of biological treatment processes, usually an activated sludge or fixed-film microbial reactor along with secondary settling, following a primary treatment system. Removals of 85-90% BOD and suspended solids are commonly associated with secondary treatment. Thus treatment in this range of efficiency can be referred to as "equivalent to secondary treatment" if achieved by other means such as lagoons, extended aeration, or physical/chemical treatment.

treatment system - A series of treatment units arranged in a rational sequence in order to produce a desired overall effect on a wastewater. The cumulative effects of each treatment unit are taken into account in system design.

treatment unit - A single physical, chemical, or biological step used to produce a desired effect on a wastewater which has certain known or assumed characteristics.

unit operation - A treatment unit which uses chemical or physical mechanisms as the basic means of treating wastewater.

unit process - A treatment unit which uses biological mechanisms as the basic means of treating wastewater.

Objectives

Upon completion of this module, the reader should be able to:

1. Describe the level of pretreatment for irrigation, moderate rate, and high rate land application systems.
2. List the bases for design flow rates of conventional and land application systems.
3. List a range of % removal efficiencies for BOD, suspended solids, and nutrients for conventional, advanced, and land application systems.
4. Explain in terms of removal efficiencies the cost comparisons summarized in Figure 7, "Comparison of Costs".

Introduction

Types of Waste Treatment That May Precede Land Application

Many different kinds of waste treatment units and systems have been developed to meet the needs of society. Each carries out certain functions, i.e., settleable solids removal, organic waste matter removal, enhancement of subsequent treatment processes, pathogen destruction, dissolved solids removal, etc. Systems are composed of some combination of physical, chemical, and biological units. Some units make use of more than one of these treatment mechanisms. The following are discussed as possible pretreatment steps to land application: 1) preliminary, 2) primary, 3) secondary, 4) disinfection, 5) advanced waste treatment (AWT).

Waste sometimes receives pretreatment before being applied to the land.

1) Preliminary Treatment:

The purpose of preliminary treatment is to remove large and dense objects found in raw sewage. These might include such materials as sand, gravel, wood, and rags. Figure 1 is a typical flow diagram depicting those processes that could be considered as preliminary treatment. Not all may be used at a specific plant.

Preliminary treatment removes large, dense objects from raw sewage.

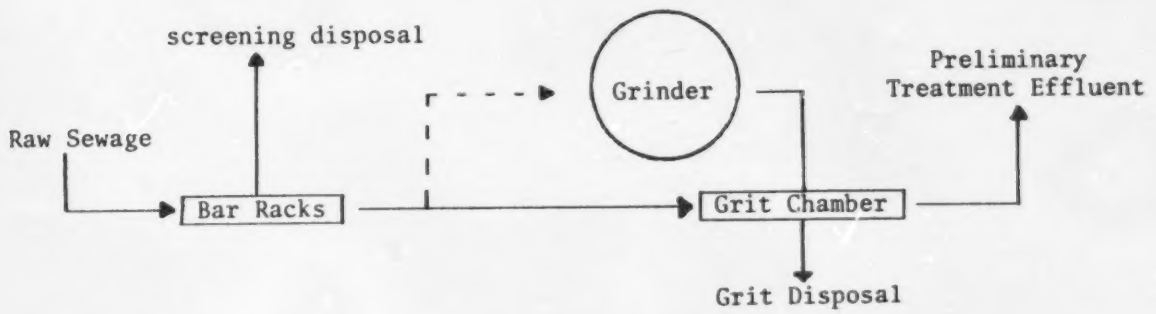


Figure 1. Typical preliminary treatment flow scheme.

The solid material separated in preliminary treatment is saturated with raw sewage, making it quite objectionable. These solids are generally disposed of in landfills or by incineration. The remaining wastewater will be comprised of less than 1% solids which may be easily pumped and conveyed by conventional water handling equipment.

At this point the only pollutants that have been removed from the wastewater stream are large objects that can be easily removed and which may damage or clog subsequent wastewater handling equipment such as pumps, pipes, valves, weirs, sprinkler nozzles, in-line filters. The land application system will benefit from low maintenance as a result of efficient preliminary pretreatment.

Good preliminary treatment reduces maintenance of wastewater handling equipment by removing objects that could damage or clog equipment.

In Braunsweig, Germany, where land application of domestic sewage has been practiced since the late 1800's, this is the only pretreatment utilized. As will be shown in Module 16, "Legal Aspects", there are few instances in the United States where pretreatment for land application systems would be acceptable at this level. However, this is an area where more research data from full scale systems is needed. With this kind of data, pretreatment restrictions would probably be relaxed considerably. Requirements for pretreatment, where disinfection is of little concern, would be based upon system clogging potential and the maintenance program. Screening may be all that is required for smooth operation.

2) Primary Treatment Separates Solids

Primary treatment is generally considered to be initial sedimentation of large particles. Many engineers think of preliminary treatment as a part of primary treatment. The distinction is made here so that evaluation of each with respect to land application systems will be more clear.

The purpose of conventional primary treatment is to further separate settleable and floatable solids. Items which generally pass through preliminary treatment but are separated out in primary treatment are fats, greases, oils, soap, small pieces of rubber, cork, wood and plastics, vegetable and fruit debris, and settleable fecal matter. The floatable items are

Floatable items are skimmed off and dense particles that have settled are removed in conventional primary treatment.

mechanically skimmed from the sedimentation tank surface while the more dense particles settle and are removed as primary sludge. This process removes 50 to 65% of the suspended solids and 25 to 40% of the 5-day biological oxygen demand (BOD_5) from the wastewater stream. Figure 2 outlines typical processes in primary treatment.

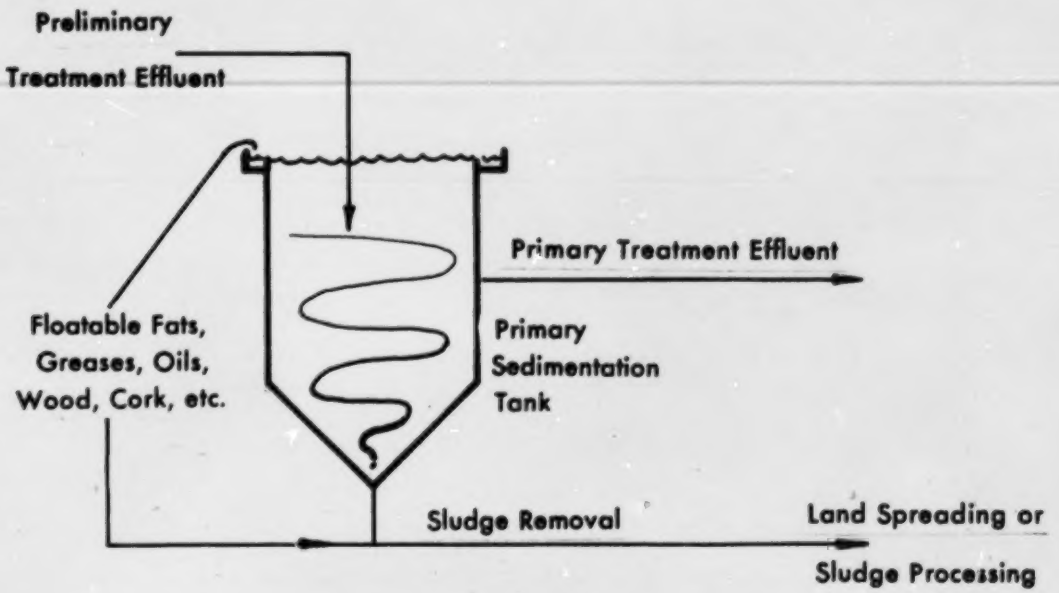


Figure 2. Primary treatment flow scheme.

Primary treatment is a valuable separation process where moderate rate land application systems receive the final effluent, i.e., rapid infiltration systems receiving between 5 and 60 inches per week. Physical and biological clogging has been known to be a problem where excessive organics are applied to the soil. Primary treatment removes a substantial amount of these organics. In systems where a crop is to be maintained, lower application rates are required, thus organic clogging may not pose a threat to the

Primary treatment removes settleable organics; their removal may be unnecessary if wastewater is being applied to crops which can readily assimilate them.

system operation. The organics that would normally be separated in primary treatment are readily assimilated within the soil/plant treatment medium. Primary treatment would not be needed as a pretreatment to land application systems where crop maintenance is part of the treatment scheme, although many crop systems operate successfully with primary pretreatment. Additional information on the fate of organics in soil systems is given in Modules 3 and 17 on "Soil as a Treatment Medium", and "Organic Matter".

3) Secondary Treatment Uses Microorganisms

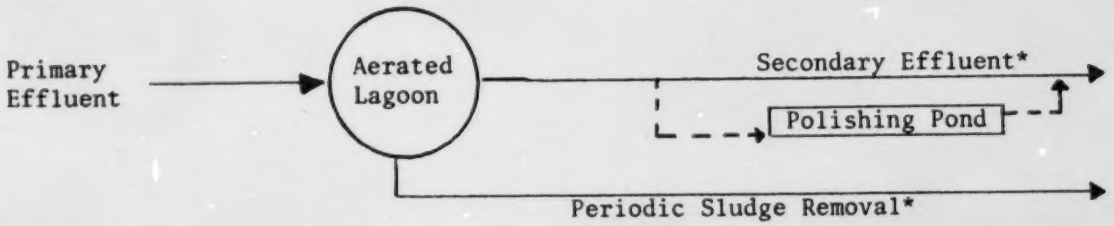
Secondary treatment systems include biological treatment such as aerated lagoons, trickling filters, and activated sludge, as well as subsequent solids settling. Typical systems are shown in Figure 3. These are the types of unit processes that would be considered where the pretreatment requirement included secondary treatment.

These systems are designed to removed suspended solids, particulate organics, and soluble organics from the wastewater.

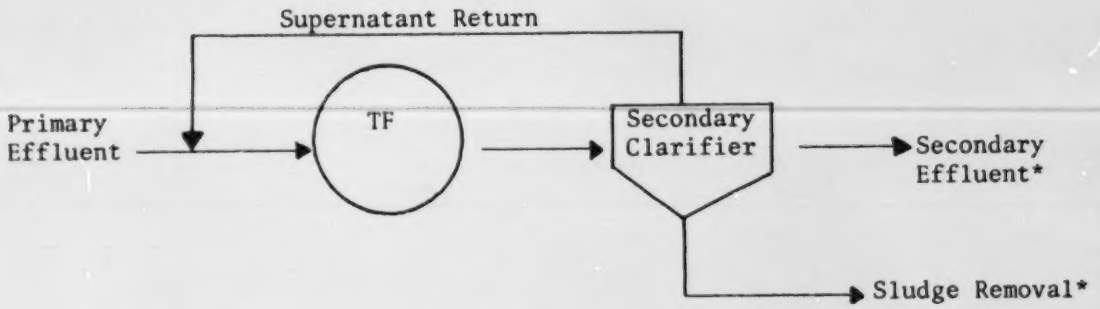
Secondary treatment removes suspended solids and soluble organics.

These processes involve a microbial population capable of using the wastewater organics as food. In doing this, the waste organics are transformed into carbon dioxide or more stable solids which are easily separated from the waters by secondary sedimentation. The sludge resulting from these aerobic processes is separated from the wastewater stream in subsequent settling basins. The quality of the secondary effluent is directly related to the effectiveness of the sedimentation tank in removing these solids. The sludge from these types of systems may be further handled through aerobic or anaerobic digestion, chemical treatment and/or a dewatering process before final residue disposal by

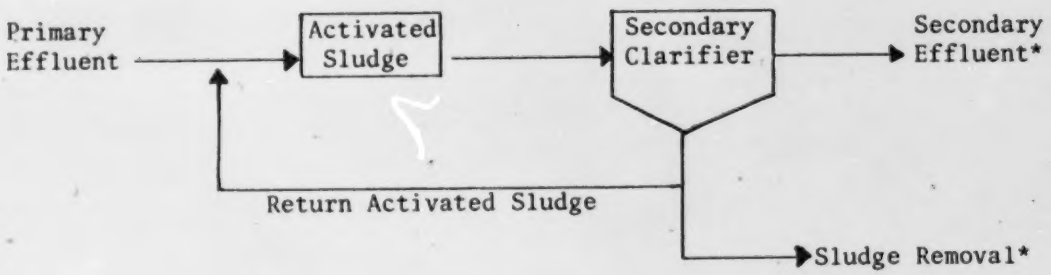
In secondary treatment, microorganisms metabolize waste organics transforming them into CO_2 or more stable solids.



(A) Aerated Lagoon



(B) Trickling Filter



(C) Activated Sludge

* All available for land application at this point. Sludges may go to digestion process.

FIGURE 3. Secondary treatment flow schemes

ocean dumping, disposal in a landfill, spreading on the land, etc.

The removal of organics in secondary treatment enchances the effluent value as an influent to high rate (greater than 5 feet per week) land application systems. Although 5 to 10% of the suspended solids may still remain in secondary effluent, the water at this point often has a clarity approaching tap water. Of the systems reveiwed by Pound and Crites (1973), all high rate land application systems received secondary treatment. Odor control is also accomplished by the aerobic biological oxidation in secondary treatment.

Secondary treatment is suited to high rates of wastewater application.

The use of secondary treatment as a pretreatment to land application systems not utilizing a high loading rate would not appear to be necessary to protect the soil from organics. The biological oxidation of organics occurs as readily in the soil system as it does in the controlled environment of secondary treatment (see Module 17 - "Organic Matter"). The reduction of BOD and suspended solids in the wastewater has been higher from land application systems than from conventional secondary treatment. Where odor control is a problem, secondary treatment or some form of aeration pretreatment will probably be required.

The soil can perform the breakdown of organics as readily as conventional secondary treatment systems can.

4) Disinfection Kills Pathogens

Disinfection of wastewater effluents has been practiced for many years in an attempt to rid society of disease causing organisms. The organisms of greatest concern to the human are pathogenic bacteria, viruses, and amoebic cysts. These are the causes of diseases such as typhoid, cholera, dysentery, and infectious hepatitis. The use of chlorine and its compounds as a disinfectant may remove greater than 99% of the bacteria and virus population in the wastewater. (See Module 9, "Pathogens"). Other types of disinfection have been used but have not been as cost

Disinfection of wastewater kills bacteria, viruses.

effective. Most experience with alternate methods has been gained in Europe with ozonation. However, this pertains to potable water treatment, as wastewater disinfection is uncommon there.

Chlorination system design is based upon rapid initial mixing, adequate contact time, and the resulting chlorine residual in the effluent. In the past, emphasis has been placed on contact time, but guidelines base the effectiveness of disinfection upon the resulting chlorine residual. Chlorine residuals found in typical wastewaters vary from 0 to 3.0 mg/l. Free chlorine residuals of 0.5 mg/l are recommended where virus inactivation is needed (Robson, 1975). Effective chlorination requires that the wastewater have low suspended solids and organic concentrations, equivalent to secondary effluent, for the reasons given below.

Since chlorine is a powerful oxidation agent, it is also consumed in many side reactions with reduced organic matter and inorganics such as ammonia. These reactions may quickly eliminate the free chlorine residual and decrease the killing action of the chlorine. This raises one of the complicated issues of land treatment systems. As was noted earlier, secondary treated effluents may not be required for organic removal, since soils have significant organic assimilation capacities. Yet in order to obtain efficient pathogen destruction at reasonable chlorine dosages, it is necessary to first remove other compounds with which chlorine will react. Where the public health problem is controlled in another manner, it might be concluded that neither secondary treatment nor chlorination is necessary. This is another area where full scale operating data is needed.

Because of chemical reactions with organics and ammonia before killing power can be exerted, high removals of these materials must be achieved if chlorination is to be effective.

With respect to land application systems, crop growth has been shown to suffer under 0.5 mg/l

chlorine residual in the irrigated wastewater (Reed, 1975). Trout and salmon as well as organisms on which fish feed cannot withstand a chlorine residual greater than 0.01 mg/l, whereas 0.002 mg/l should protect most aquatic organisms (Robson, 1975). Judging from the information presented above it appears that pathogen inactivation and optimum crop response cannot both be achieved utilizing chlorine as a disinfectant.

Chlorine has bad effects on crops, higher aquatic animals.

Ozone has been used successfully as an effective wastewater disinfectant. Although it is more expensive to use than chlorine compounds, it leaves no residual to degrade the receiving sink. If disinfection is required of influents to land application systems, ozone may present a technically feasible alternative which will safeguard the application area and discharge site as well as ensure an adequate pathogen kill.

Ozone, although costly, may be best for disinfecting wastewater prior to land application.

5) Advanced Wastewater Treatment (AWT) Removes Soluble Substances

Advanced wastewater treatment or tertiary treatment of wastewater refers to the treatment processes above and beyond conventional preliminary, primary, and secondary treatment with chlorination. Generally, these treatment processes are designed to remove soluble substances such as dissolved solids and organics, which normally escape secondary treatment. In some areas further SS reduction through filtration may be referred to as tertiary treatment. Some of these systems include:

1) Nitrification - denitrification (nitrogen removal)
2) Phosphorus precipitation (phosphorus removal)
3) Activated carbon adsorption (soluble organics removal)
4) Ion exchange (removal of hardness-causing cations)
5) Reverse osmosis (dissolved solids removal)
6) Distillation (dissolved solids removal)

The quality of effluents realized from tertiary treatments 1), 2), and 3) above can usually be exceeded by land application systems. However, systems 5) and 6) reduce the total dissolved salts concentration and can produce a high quality water suitable for drinking. It should be noted here that this represents another complex area. For example, a secondary treatment facility may prove to be slightly more cost effective than land application treatment. However, the land application system may produce a superior effluent. In comparing AWT with land application systems, the total costs must be weighed against the effluent quality required through treatment. Effluent qualities and costs are discussed in subsequent sections.

Land application can exceed results of tertiary treatment in producing a quality effluent except in the area of reducing dissolved salts concentration.

Law Requires Consideration of Land Application System as a Waste Treatment Alternative

The application of wastes to the land for treatment and/or disposal is not a new idea. It has been happening for centuries. However, our exposure to this waste treatment alternative has been limited in the past century due to significant advances in what is now called conventional and advanced waste treatment. Present laws enacted in this country, (e.g., PL92-500, enacted in 1972) have demanded that waste treatment alternatives be investigated prior to spending federal funds for waste treatment systems. These alternatives were to include "treatment and discharge into navigable waters, land application and utilization practices, and reuse of treated wastewater" (Train, 1976). For this reason, rational design bases for land treatment systems must be used, in order to gain acceptance from funding agencies as well as the people served by the system.

Federal law requires cities and towns to investigate alternatives to conventional and advanced waste treatment.

As with other waste treatment systems, land application for treatment and/or disposal has been proved to be cost effective under varying conditions of waste characteristics, water renovation capacity

of the treatment medium, and the treatment medium cost. Three common land application systems - irrigation, overland flow, and infiltration and percolation - are briefly discussed below.

Irrigation: Irrigated agriculture has developed two main methods of dispersing water on the land, 1) surface application and 2) spray irrigation. Because wastewaters are generally greater than 99% water, it was only natural that these techniques would also be utilized in wastewater dispersal.

Pretreatment of wastes applied through irrigation methods will require, as a minimum, preliminary treatment. The effluent obtained from a waste management system utilizing preliminary treated influent and crop management is generally much lower in nitrogen, phosphorus, BOD_5 and SS than conventional secondary treatment effluents. Although systems designed specifically for BOD_5 and SS removal may not be required as a pretreatment to land application systems utilizing an appropriate crop management scheme, as of 1976, only one state, California, had specifically declared irrigation with wastewater without prior secondary treatment to be an acceptable practice (Module 16, "Legal Aspects").

Surface Irrigation systems have been developed around soil and topographic limitations. The rapidity with which water travels across the soil surface and through the soil profile defines the configuration of ditches and levees which make up the system. These ditches and levees are designed to provide as uniform an application as possible within the labor and water constraints at hand.

Wastewater management utilizing this application method is confronted with two unique problems. 1) Wastewaters, unlike typical irrigation waters, have a variety of pathogens that must be avoided.

Therefore, hand labor should be kept at a minimum in a system which ordinarily utilizes excessive hand labor. 2) The uniformity of application of surface applied waters is generally very poor without doubling the usual labor requirement.

Workers at surface irrigation systems must follow good public health and cleanliness practices due to pathogens in wastewater. Many man-hours are required to effectively operate such a system.

Spray irrigation systems were developed with the advent of the gas and electric powered pump. Although capital costs increased through their use, labor and water could be conserved. Many configurations of permanent and portable systems have since been developed to satisfy specific design and management needs.

Spray application is most efficient in terms of applying wastewater evenly to the treatment site. Spray irrigation requires less labor than surface irrigation but has another problem, aerosol drift.

Although these systems seem to have minimized labor requirements while maximizing the uniformity of application, they have also created problems specific to spray irrigation. The aerosol drift associated with sprayed wastewaters may contain pathogens. Although aerosols containing pathogens are also found around conventional sewage treatment plants, the problem is contained within a relatively small area, whereas in land application systems hundreds of acres may be involved.

In overland flow systems, wastewater is applied to smoothed grassed slopes and allowed to trickle over the soil surface for 100 to 300 feet. The effluent is then collected in a system of terraces and safely transported to a division point. After an evaluation of the effluent, it is either discharged to the receiving sink or recycled back through the system for further renovation. Although very little data have been published on this renovation technique, some cannery sites have been operating successfully for upwards of 25 years and the technique has the potential of becoming very popular. Both spray and surface irrigation methods are used to apply wastewater to the soil, therefore pretreatment requirements of overland flow systems are similar to application

systems previously outlined. However, effluents from overland flow systems have shown lower nitrogen, phosphorus and suspended solids removal. Additional treatment may be required in the treatment scheme where more efficient removal is required. One obvious combination is to use a high loading rate overland flow system preceded by preliminary treatment and followed by high rate infiltration-percolation ponds.

Rapid infiltration/percolation: The rapid infiltration and subsequent percolation of wastewater into and through the soil profile is utilized mostly with conventionally treated effluents. Very large amounts of wastewater (up to 300 ft applied per year) are either sprayed or flooded over the infiltration basin on highly permeable soils where it readily disappears. A resting period is then provided which allows biochemical reactions such as nitrification-denitrification to occur, as well as sorption of various ions. Proper management of this wetting and drying cycle may substantially remove large amounts of nitrogen from the wastewater. The sorption capacity of the soil profile will more than likely be exhausted prematurely compared to lower rate land application systems. However, a limited amount of rejuvenation of the sorption capacity occurs over time.

Rapid infiltration/percolation are high-rate systems. Those passing more than 5 feet of effluent a week need prior secondary treatment of wastewater to avoid clogging of the soil.

Pretreatment requirements utilized in rapid infiltration have fallen into two categories, 1) those systems receiving more than 5 feet of effluent per week and 2) those systems receiving less than 5 feet per week. At least secondary treatment is recommended for land application systems passing more than 5 feet of effluent per week. Clogging of the soil surface has been the predominant management problem which generated this limitation. Systems passing less than 5 feet per week have not had a recurring clogging problem when primary effluents are applied (Pound, 1973).

Effluent Qualities from Waste Treatment Systems Must be Estimated or Determined

The effluent qualities expected from established conventional and advanced wastewater treatment processes are shown in Table 1. Because these systems have controlled environments and have been used for many years, their effluents may be predetermined with reasonable accuracy. However, the environments of land application systems are not as readily controlled nor have they been monitored over a long period of time. Therefore, the treatment process efficiency and expected effluent qualities are not as easily predicted. Table 1 also estimates the design efficiencies and effluent qualities of land application systems. All conventional treatment process (including tertiary) effluents have measurable pollutant contaminants.

Effluent quality is easier to document in conventional treatment than in land application. All predictions assume proper operation and maintenance.

It is not unusual to measure phosphorus concentration equal to background groundwater concentration (approximately 0.05 mg P/1) and COD concentrations less than 5 mg/1 from land application sites. It should be emphasized that all expected removal efficiencies depend on proper operation and maintenance.

Land Treatment and Conventional Systems are Compared

Each decision that must be made with respect to waste treatment inevitably has an associated cost. The array of pollutants, treatment systems, and effluent limitations is such that addressing each alternative is a task beyond the scope of this module. However, to provide some indication of the relative costs of possible alternatives, we will utilize the information in "Municipal Sewage Treatment - A Comparison of Alternatives" (Battelle, 1974). This data is presented as one means of comparing various system options. Other references on costs of land application and conventional wastewater and sludge treatment can be found in Module 10, "Costing Land Application Systems". A concise and easily used comparison is found in the reference Pound, Crites, and Smith, 1975.

Table 1. Design efficiencies and effluent qualities of conventional and advanced waste treatment processes.

Treatment Process	Design removal effiency(%)				Effluent quality (mg/l)			
Conventional & AW treatments***	BOD	SS	P	N	BOD	SS	P	N
Preliminary treatment	0	0	0	0	210	230	11	30
Primary settling	20-40	50-65	-	-	140	110	-	-
Activated sludge	75-95	-	-	-	20	25	-	-
Trickling filter	75-90	-	-	-	30	35	-	-
Filtration	50	72	-	-	10	5	-	-
Activated carbon	60	60	-	-	4	2	-	-
Two stage lime treatment	-	-	50	-	-	-	0.5	-
Nitrification-denitrification	-	-	-	90	-	-	-	3
*Land Application Systems**								
Irrigation	98+	98+	80-99+	85+	4	5	2	6
Overland flow	92+	92+	40-80	70-90	18	18	2-7	3-9
Infiltration/percolation	85-99	98+	60-95	0-50	30	5	4	15-30

*Influent from preliminary treatment

**Pound, Crites and Griffes, 1975b

***Van Note, et al., 1975

The eleven liquid treatment strategies and twelve sludge options investigated in the Battelle study are listed in Table 2. Example process profile sheets with a description of each liquid treatment strategy are presented in the following sections. These systems were chosen because of their popularity prior to 1973 and their expected continued use in the near future. The liquid treatment strategies may be followed by any one of the twelve sludge treatment and disposal options shown. However, in Figure 6, sludge options #5 and #11 were chosen to use in this illustration.

Battelle study examined 11 liquid treatment strategies and 12 sludge options.

This study also compares the labor, energy requirements, and costs of the eleven treatment strategies as well as the removal of BOD, suspended solids, nitrogen, phosphorus, heavy metals, and the resultant sludge volume upon completion of treatment.

Battelle Study Examines Liquid Treatment Strategies

The first example consists of preliminary and primary treatment followed by land application of the effluent as illustrated in Figure 4.

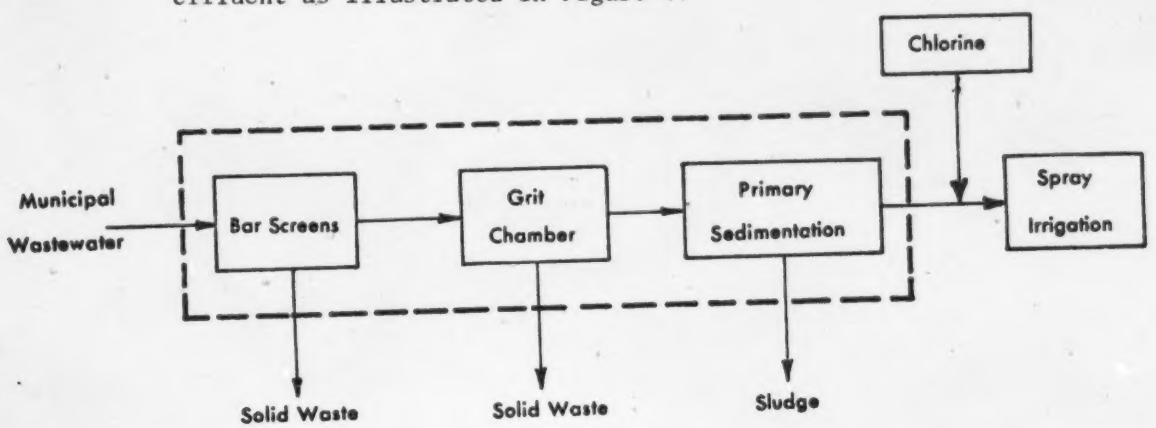


Figure 4. Primary treatment with land disposal of liquid effluent (Strategy 1 in Table 2).

Table 2. Possible wastewater treatment strategies and sludge treatment options

		Liquid treatment strategies
*1		Primary treatment with land application of liquid effluent
2	a.	Waste stabilization lagoon with surface water discharge
*	b.	Waste stabilization lagoon with spray irrigation
3		Trickling filter with surface water discharge
*4		Trickling filter with land application
5		Activated sludge with surface water discharge
*6		Activated sludge with land application
7		Biological - chemical treatment
8		Activated sludge - coagulation - filtration
9		Tertiary treatment
10		Physical - chemical treatment
11		Extended aeration

	Sludge treatment and disposal options
1	Sludge thickening, chemical conditioning, vacuum filtration, incineration, and landfill
2	Chemical conditioning, centrifuge dewatering, incineration, and landfill
3	Sludge thickening, conditioning by heat treatment, vacuum filtration, incineration, and landfill
4	Sludge thickening, digestion, sand drying beds, and landfill
5	Sludge thickening, digestion, and land spreading
6	Sludge thickening, digestion, and ocean dumping by pipeline
7	Sludge thickening, digestion, chemical conditioning, vacuum filtration, and landfill
8	Sludge thickening, digestion, chemical conditioning, vacuum filtration, and ocean dumping by barging
9	Chemical sludge thickening, vacuum filtration, incineration and reuse, and landfill of wasted residue
10	Chemical sludge thickening, vacuum filtration, recalcination and reuse, and landfill of wasted residue
11	Chemical sludge thickening centrifuge dewatering, incineration and landfill
12	Chemical sludge thickening, centrifuge dewatering, recalcination and reuse, and landfill of wasted residue

*Land application of treated effluent
From Battelle Memorial Institute, 1974

Another common alternative presently adopted in many systems is the use of a waste stabilization pond followed by land application (Figure 5). This system may be incorporated in areas where long term storage is required.

Land application can follow use of a waste stabilization pond in areas where long term storage is necessary.

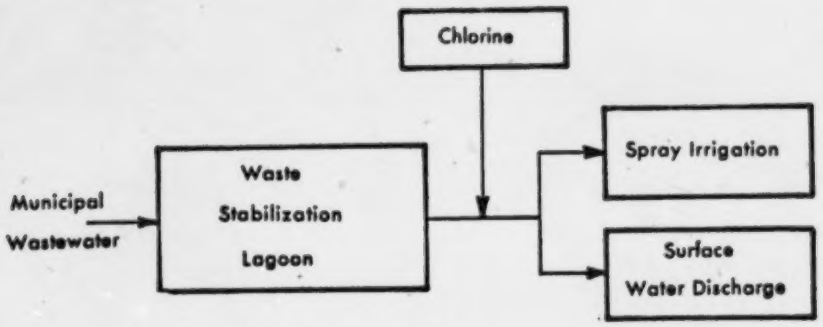


Figure 5. Waste stabilization lagoon (Strategy 2 in Table 2).

The third and fourth strategies listed in Table 2 consist of primary and trickling filter treatment followed by discharge of surface water or land application, respectively.

The fifth and sixth strategies consist of primary and activated sludge treatment followed by discharge to surface water and land application, respectively. Activated sludge is presently the single most popular type of secondary treatment process being designed for municipalities. The complete mix activated sludge process was selected on its ability to consistently achieve high quality effluents. Furthermore, it is presently considered to be the superior method of biological treatment consistent with present and future treatment requirements as set forth in the Federal Water Pollution Control Act Amendments of 1972.

Activated sludge process is a popular and effective method of secondary treatment.

The seventh strategy consists of activated sludge treatment with alum addition and nitrification-denitrification followed by discharge to surface water. Land application of effluent water is not considered for this treatment sequence since nutrient removal would

be superfluous if that mode of treatment were utilized. The nutrient removal capacity is presently added to protect surface waters to which intended discharges are to be made. This facility probably is representative of the better technologies currently available for organics, nitrogen and phosphorus control.

Certain liquid treatment strategies are not suited as pretreatment for land application because their level of treatment would be comparable to land treatment.

The eighth strategy consists of activated sludge treatment and coagulation-filtration followed by discharge to surface waters. Once again, land application was not considered as an ultimate disposal option since its use would preclude the necessity for the high level of treatment afforded by the addition of coagulation-filtration.

The ninth strategy consists of activated sludge, coagulation-filtration, carbon sorption, and zeolite ammonia removal followed by discharge to surface waters.

The tenth strategy consists of coagulation-filtration and carbon adsorption followed by discharge to surface waters.

The eleventh and final strategy evaluated consists of extended aeration followed by surface water discharge of liquid effluents. Extended aeration can provide relatively high quality water if properly designed, hence effluents may be disinfected and released to surface water without further treatment. However, in practice extended aeration plants seldom perform to the theoretical capability of the process, hence their effluents should be considered for land application in the same manner as activated sludge effluents in the sixth strategy, above.

Costs are compared for the treatment strategies involving application of the treated liquid to the land (1, 2b, 4, and 6 in Table 2) and AWT processes. These include primary and secondary pretreatments prior to land application. The least cost sludge options were added to all of the treatment strategies to approximate the total cost of the waste treatment system. A

comparison of these treatment and sludge handling costs is shown in Figure 6. These are average 1973 values selected from the Battelle study which gives a range of total operation and capital costs of up to ± 6¢/1000 gal. from the values in Figure 6 for some strategies.

Cost of land application of secondary effluent is comparable to AWT.

Note that the cost of land application of primary and secondary pretreated effluents are approximately the same as AWT. The need for such a highly pretreated effluent prior to land application is questionable. In most cases, preliminary pretreatment prior to land application will result in an acceptable effluent quality, generally equal to or better than AWT. Preliminary treatment costs are estimated at 2.7¢, 0.84¢ and 0.4¢/1000 gal. for 1, 10, and 100 mgd plants respectively (Van Note, 1975). These costs did not include facilities such as offices, labs, pump stations and outfalls. The dashed horizontal line, "Land Application Costs", of Figure 6 varied from 21 to 31¢/1000 gallon as presented in the Battelle Study. It is apparent here that land treatment systems are very cost effective for small daily flows (.1, 1, 10, mgd) where high quality influents are not required.

Preliminary treatment followed by land application usually results in an acceptable effluent quality, equal or better than advanced waste treatment.

Cost of Acceptable Effluent Varies

The cost of obtaining an acceptable effluent quality in waste treatment varies significantly, depending upon the influent quality, the treatment process selected, and the receiving sink. The quality of effluent required to meet the 1977 goals (for "best practicable technology") established by PL 92-500 is that of secondary treatment, i.e., 30 mg/l BOD_5 and SS, where discharge is to navigable waters. However, land application systems must meet groundwater quality requirements as set forth by PL 93-523, "Safe Drinking Water Act", for inorganic and organic chemicals, and microbiological contaminants (Train, 1976).

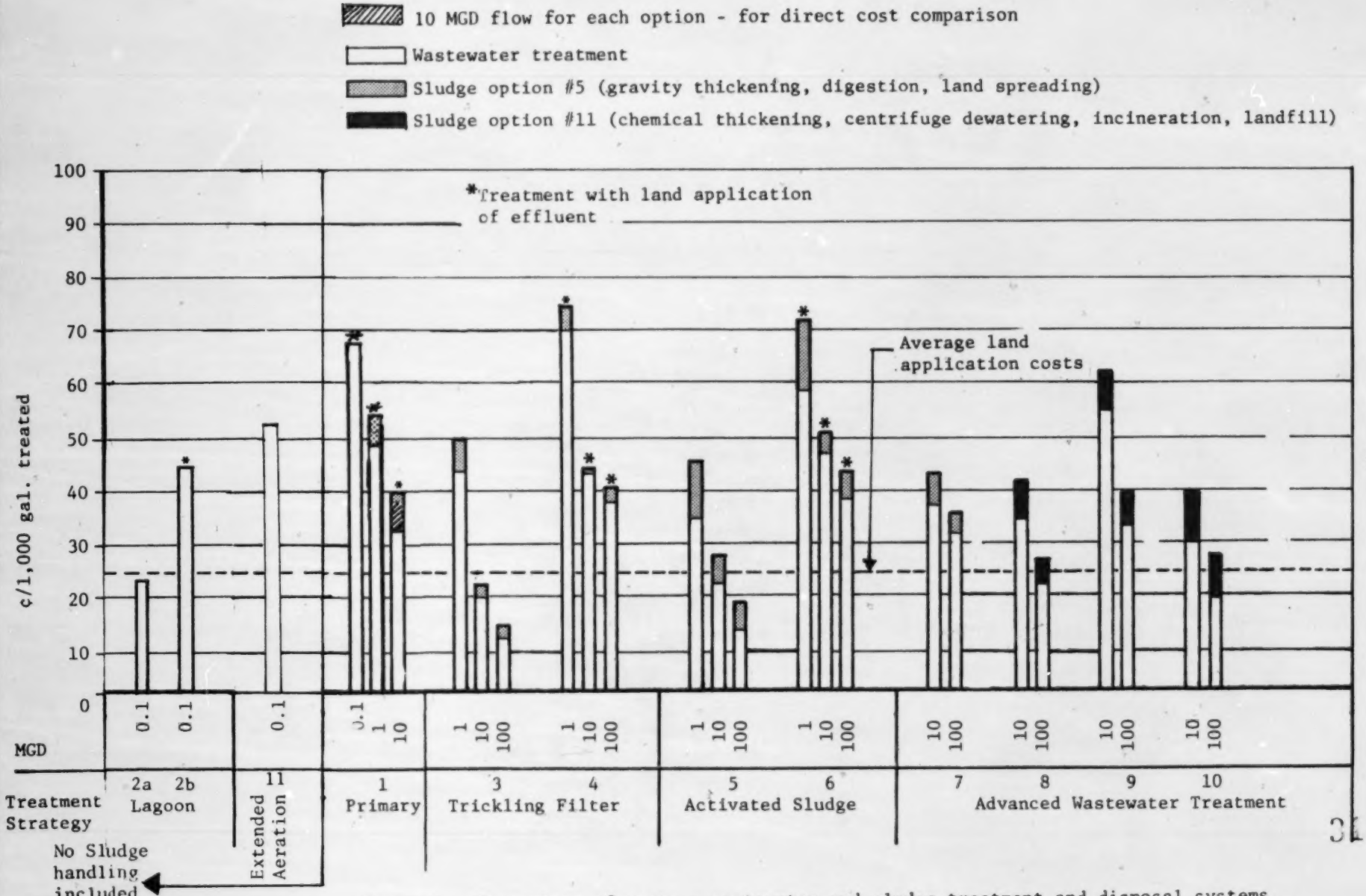


Figure 6. Comparison of costs - wastewater and sludge treatment and disposal systems.

Table 3 compares unit treatment process costs and expected effluent qualities. From this table many different wastewater schemes may be assembled. The costs may be accumulated and the effluent qualities estimated.

Design Important in Land vs. Conventional Treatment

Although this module cannot provide a complete review of the relationships of waste characteristics to acceptable design parameters, two additional factors become apparent. These factors may have a significant impact on the decision to use land application systems. The first issue deals with the design flow and overall size of the treatment facility. The second issue is more of a caution to be sure that economic comparisons are made between similar units.

Land Application Has Greater Flexibility

The commonly accepted basis for the design flow of domestic wastewater is related to the maximum variations in flow rates that can be expected for different sized populations. These flow may vary over a wide range. For example, the peak flow for a design population of 10,000 would be 2 1/2 to 3 times the average daily flow. Thus a secondary treatment facility to serve this population would be built to handle a design flow of 3 MGD even though its average present flow is much less.

To some, this may seem to be an overly conservative approach. However, when the problems of obtaining public approval to enlarge the bonded indebtedness of communities are considered, along with the problems of extensive plant expansion, it is clear why the peak flow serves as a basis for design. One attempt to change this has been to include flow equalization basins. However, operational problems have come about in some installations and they are not widely implemented.

Table 3. Unit treatment processes - effluent qualities and costs (after Van Note, R. H., 1975 except as noted)

	Estimated Effluent						¢/1000 gal		
	BOD	TSS	TP	TKN	TN	pH	1 mgd	10 mgd	100 mgd
Untreated Wastewater	210	230	11	30	30	7.3			
Conventional Treatment									
Preliminary treatment - bar rack, grinding, grit chamber									
	210	230	11				2.7	.84	.4
Pumping - 30 ft TDH									
	210	230	11				6	2.6	1.3
Primary sedimentation - conventional (influent from preliminary treatment)									
	140	110	10				6.8	1.7	.8
Trickling filter - conventional (influent from primary sedimentation)									
	30	35	9				>10	4.8	3.5
Activated sludge - conventional (influent from primary sedimentation)									
	20	25	8				19	7	4
Sludge Treatment									
Anaerobic digestion (sludge influent from primary and secondary treatments)									
influent 5%S 70% VS							2.8	1.3	1.0
effluent 4%S 54% VS							4.2	1.0	.57
Advanced Wastewater Treatment									
Filtration									
Estimated influent	20	18	2.0						
effluent	10	5	1.0				11	5.5	2.5
Activated carbon - conventional (influent from filtration)									
	4	2	0.8				22	15	10
Two stage tertiary lime treatment -(influent from trickling filter)									
	10	10	0.5	29	30		>10.0	3.4	1.5
Biological nitrification (influent from trickling filter)									
	10	15		1	30		11	4.6	2.9
Biological denitrification (influent from biological nitrification)									
	15	16		1	3		9.5	4.4	3.6
Ion exchange (influent from filtration)									
				1	1		14	8.7	5.8
Ammonia stripping (influent from two stage tertiary lime treatment)									
				2	3		10	4.8	3.7
Disinfection (influent from any process, D.T. >15 min. ≤200 F.C./100 ml)									
							2.8	1.3	1.0
Land Application Systems*									
Irrigation	4	5	1		5				
Surface							25	14	
Spray - solid set							30	20	
- center pivot							23	14	
Overland flow (4 ipw)	17	18	4		2		20	12	
Rapid infiltration (12 ipw)	2	5	3		23		13	6	

*Pound, Crites and Griffes, 1975a

The design flow basis for land treatment systems is not necessarily subject to the same analysis, because the systems are often less sensitive to flow variations. This is especially true for those facilities that include storage periods of 10 to 20 weeks. These storage units can be viewed as extremely large equilization basins and can lend flexibility to the operation. In many cases it will be acceptable to size the land application systems on the basis of average daily flow rather than 2 1/2 to 3 times the average daily flow for the design population. This would result in a design flow of less than half that of conventional treatment.

Conventional treatment systems must be sized for peak flows of 2 1/2 to 3 times average daily flow for the design population. Land application is more flexible; systems may be planned on average daily flow.

Another positive aspect of land application systems is their flexibility in terms of expansion. Although it would be wise to purchase the total quantity of land required for the design flow and to build in major components such as pumping stations, it may not be necessary to set up the entire system. For example, if the present average flow were half the design flow estimated 20 years hence, it might be recommended that only two thirds of the site be developed for the system, with the remainder developed when the need arises. This type of expansion is more feasible with land treatment systems than with conventional systems because of the low capital costs involved in the expansion of such facilities as a spray irrigation field.

It is generally easier to expand a land application system than a conventional treatment system.

Costing Based on Cents per 1000 Gallons Designed or Treated?

The second topic to note in comparing conventional treatment to land treatment is the economic basis of the comparison. Most of the costing that has been developed expresses the treatment costs on the basis of ¢/1000 gallons of wastewater treated. For the more capital intensive conventional systems this value is most often in terms of ¢/1000 gallons of wastewater design flow. The cost per 1000 gallons

of wastewater treated may be considerably higher than this value. If the land application system can be gradually expanded with increasing flows, then the cost can be expressed in terms of unit volume of wastewater actually treated, rather than being based on a future design flow.

Gradual expansion of land application systems with increased flow means less cost per 1000 gallons treated.

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TREATMENT SYSTEMS, EFFLUENT QUALITIES AND COSTS

Objectives

Upon completion of this module, the participant should be able to:

1. Indicate the level of pretreatment required by law in most states for land application.

2. Indicate the level of pretreatment that may be necessary for successful operation of irrigation, overland flow, and two types of rapid infiltration.

3. Indicate the removal efficiencies for BOD_5, suspended solids, and nutrients for secondary treatment, advanced wastewater treatment and the three types of land application systems.

4. In general the cost of land application of primary and secondary treated effluents are the same as advanced waste treatment. However, this may not tell the complete story concerning cost effectiveness. Why?

RETURN TO LESSON PACKAGE

Script to Accompany the A-T

TREATMENT SYSTEMS, EFFLUENT QUALITIES AND COSTS

Module 4
January, 1978

TREATMENT SYSTEMS, EFFLUENT QUALITIES, AND COSTS

(Slide 1). This lesson provides an overview of treatment processes that are being commonly employed (Slide 2), including land treatment (Slide 3), to treat wastewater. Included in this lesson is a description of the processes, the resultant effluent qualities, and the associated costs. There is also a discussion of the value of the conventional processes as a pretreatment to land application. The objectives for this lesson are located in the envelope labelled "Objectives" that was with the tape. Find the envelope, stop the tape recorder and study the objectives (Slide 4). You may keep the objective list for reference during the lesson.

Wastewater essentially went untreated until the eighteen hundreds when, during the cholera epidemics, the connection between germs and disease was made. As slides 5 and 6 indicate, wastewater treatment technology has advanced to the point where water for swimming and even drinking can be extracted from sewage. The information in this lesson provides an overview of existing systems so that one can compose reported process efficiencies for common pollutant removals, their associated costs, and the function they may serve in treatment schemes which employ land application.

Many different kinds of waste treatment systems have been developed to meet the needs of society. Each carries out certain functions some of which are listed in Slide 7. Systems are composed of some combination of physical, chemical and biological units. Some units make use of more than one of these treatment mechanisms. The steps listed in Slide 8 are considered as possible pretreatment steps to land application. The preliminary, primary, and secondary steps are labelled conventional treatment procedures throughout this course.

Slide 9 indicates a flow diagram depicting typical processes that could be considered as preliminary treatment. The purpose of preliminary treatment is to remove large and dense objects found in raw sewage. These might include such materials as sand, gravel, wood and rags. Not all of the processes in Slide 9 would necessarily be used at a particular plant.

The solid material separated in preliminary treatment may contain raw sewage making it quite objectionable. These solids are disposed of in land-fills. The remaining wastewater will be comprised of less than 1% solids which may be easily pumped and conveyed by conventional water handling techniques.

As Slide 10 indicates, preliminary treatment removes only large objects that may damage or clog the subsequent wastewater handling equipment, that is pumps, pipes, valves, weirs, sprinkler nozzles, and in-line filters. All systems, including land application systems, will be more maintenance free as a result of efficient preliminary pretreatment.

Slide 11 is a photo of the land application system in Braunsweig, Germany. This system has been operating since the late 1800's with only preliminary treatment utilized before land treatment. Legally, there are few instances in the United States where pretreatment at this level for land application systems would be acceptable. However, this is an area where more experience with full scale systems is needed.

Primary treatment is generally thought of as initial sedimentation of large particles (Slide 12). Preliminary treatment is often thought of as a part of primary treatment. The distinction is made here so that evaluation of each with respect to land application systems will be more vivid.

The flow scheme for primary treatment is illustrated in Slide 13. Notice that floatable and settleable materials are removed in this treatment. This is the main purpose of primary treatment. Items which are generally separated out are fats, greases, oils, soap, small pieces of rubber, cork, wood, plastics, vegetable and fruit debris, and settleable fecal matter. As Slide 14 shows, the floatable objects are mechanically skimmed from the tank surface while the more dense particles settle and are removed as primary sludge. Slide 15 indicates the design removal of primary settling and the typical influent and effluent quality of municipal sewage passing through this system. Notice that only about 25% of the nitrogen and about one-third of the phosphorus is removed in primary treatment. The nitrogen and phosphorus that is removed is tied up in the solids and insoluble liquids that the separated in primary treatment. They are not included in the design removal because the process is designed to remove the solids and insoluble liquids.

As Slide 16 indicates, primary treatment is a valuable separation process where moderate rate land application systems receive the final effluent. These systems are those which apply between 5 and 60 inches of wastewater per acre per week. Primary treatment removes a substantial amount of organics which can clog a moderate rate system (Slide 17). Primary treatment may be unnecessary in lower rate systems in which a crop is irrigated.

The organics that would normally be separated in primary treatment are readily broken down in the soil and plant treatment medium. For further information concerning organics see Module 3, "Soil as a Treatment Medium", and Module 17, "Organic Matter" (Slide 18).

Secondary treatment systems include biological treatment such as aerated lagoons, trickling filters, and activated sludge. Slide 19 indicates typical secondary treatment flow schemes. Notice that all of the secondary systems yield a sludge that must subsequently be treated as part of the waste treatment scheme. The types of unit processes indicated in Slide 19 are the types that would be considered where the pretreatment requirement for land application was secondary treatment. Secondary treatment, however, is not always necessary prior to land application.

Secondary treatment is designed to remove suspended solids, particulate organics, and soluble organics from the wastewater, as is shown in Slide 20.

These processes involve a microbial population capable of using the wastewater organics as food (Slide 21). In doing this, the waste organics are transformed into carbon dioxide and more stable substances. The sludge resulting from these aerobic processes is separated from the wastewater stream in the secondary settling basins (Slide 22). The quality of the effluent is directly related to the effectiveness of the sedimentation tank in removing these solids. The sludge from these types of systems may be further handled through aerobic or anaerobic digestion and/or a dewatering process before final disposal in a landfill by spreading on the land, or other disposal methods.

As Slide 23 indicates, the removal of organics in secondary treatment enhances the effluent value as an influent to high rate land application systems. The wastewater after secondary treatment often has a clarity approaching tap water. Odor control is also accomplished by the aerobic biological oxidation in secondary treatment.

Secondary treatment appears to be unnecessary for land treatment systems not using a high rate of application both from the point of view of the treatment obtained and the smooth operation of the land treatment system. The reduction of BOD and suspended solids in the wastewater has been higher with land treatment systems than with conventional secondary treatment as is indicated in Slide 24. As a side benefit, with land application, there is no sludge by-product to treat.

Disinfection of wastewater (Slide 25) has been practiced for many years in an attempt to rid society of disease caused by pathogenic bacteria, viruses, and amoebic cysts. The use of chlorine and its compounds as a disinfectant may remove more than 99% of the disease causing organisms in the wastewater. (For further information see Module 9, "Pathonogens") (Slide 26). Since chlorine is a powerful oxidizing agent, however, it is also consumed in many side reactions with reduced organics and inorganics such as ammonia. Because these reactions may quickly eliminate the free chlorine residual and decrease the killing action, the equivalent of secondary treated effluent must be produced for disinfection to be cost effective. The differences in the amount of chlorine necessary for effectiveness are indicated in Slide 27.

The reduction in organics necessary for effective disinfection raises one of the complicated issues of land treatment systems. As was noted earlier, secondary treated effluents may not be required for land treatment. Yet in order to obtain efficient pathogen destruction at reasonable chlorine dosages, it is necessary tofirst remove other compounds with which chlorine will react. Where the public health problem is controlled in another manner it might be concluded that neither secondary treatment nor chlorination is necessary, saving considerable treatment cost (Slide 28). This is an area where there is some operating data from established sewage farms in Europe and Australia, but full scale research data are necessary. This is especially important because crop growth has been shown to suffer under 0.5 mg/l of chlorine residual in the irrigated wastewater. This indicates that both bacterial inactivation and optimum crop response may not be achieved utilizing chlorine as a disinfectant.

Ozone has been used successfully as an effective wastewater disinfectant. Although it is more expensive to use than chlorine compounds, it leaves no residual to effect crops or degrade the soil (Slide 29). If disinfection is required of influents to land application systems, ozone may present a technically feasible alternative which will safeguard the application area and discharge site as well as insure an adequate pathogen kill. Disinfection, however, is not normally necessary prior to treatment in a well managed land application system.

Advanced wastewater treatment or tertiary treatment of wastewater refers to the treatment processes that are generally designed to remove soluble substances. As can be inferred from Slide 30, these substances normally

escape secondary treatment. The quality of effluents realized from the first three treatments in this slide can usually be exceeded by land application systems -- that is nitrogen removal, phosphorus removal, and soluble organics removal. Systems 5 and 6 in Slide 30, although not widely used, can produce a high quality water suitable for drinking. It should be noted that this represents another complex area as indicated in Slide 31. A secondary treatment facility may prove to be slightly more cost effective than land application treatment. The land application system, however, may produce a superior effluent. Land application compares in cost to secondary treatment and produces effluent comparable to tertiary treatment. The total costs must be weighed against the effluent quality required through treatment. Effluent qualities and costs are discussed in a subsequent section.

As with other waste treatment systems (Slide 32), land application has been proven to be cost effective under varying conditions of waste characteristics, water renovation capacity of the treatment medium, and the treatment medium costs. Three common land application systems -- irrigation, overland flow, and infiltration-percolation -- are briefly discussed in this section (Slide 33).

Irrigated agriculture has developed two main methods of dispersing water on the land (Slide 34). These are surface irrigation and spray irrigation. Because wastewaters generally contain more than 99% water, it was only natural that these techniques also be utilized in wastewater dispersal.

Pretreatment of wastes applied through irrigation methods will require, as a minimum, preliminary treatment (Slide 35). There are special circumstances that would indicate the need for secondary treatment as a pretreatment. As of 1976, however, only California has specifically declared irrigation with wastewater without secondary treatment to be an acceptable practice.

The rapidity with which water travels across the soil surface and through the soil profile defines the configuration of ditches and levees which make up a surface irrigation system, like the one in slide 36. These systems are often called ridge and furrow systems. The ditches and levees are designed to provide as uniform an application as possible within the labor and water constraints at hand.

Wastewater management utilizing this application method is confronted with two problems. These are that hand labor should be kept to a minimum because of the presence of pathogens (Slide 37). This problem manifests

itself in an agricultural system that is traditionally labor intensive. A second problem is that the uniformity of application of surface applied waters is generally poor without a great increase in labor requirements. In general, workers at surface irrigation systems utilizing wastewater must be trained to follow good public health and cleanliness practices.

Spray irrigation systems, like the one in Slide 38, were developed with the advent of the gas and electric powered pump. Although capital and energy costs are higher with this system, labor and wastewater are conserved. There are many configurations of permanent and portable spray irrigation systems only one of which is shown in this slide.

Although these systems minimize labor and maximize the uniformity of application, they have created their own specific problems. The aerosol drift which can be seen in Slide 39, associated with sprayed wastewaters may contain pathogens. Although aerosols containing pathogens are also found around conventional sewage treatment plants, the aerosol generation in conventional systems would be produced in only a few acres. As is indicated in Slide 40, several hundred acres may be involved in land application with a concomitant increase in the drift area. In these days of rising energy costs, the energy intensive systems, such as spray irrigation may become less cost effective.

In overland flow, shown in Slide 41, wastewater is applied to a smooth grassed slope and allowed to trickle over the soil surface for 100 to 300 feet. The effluent is then collected in a system of terraces and safely transported to a collection point. The effluent is either discharged to the receiving sink or recycled back through the system for further renovation. Although very little data has been published on this renovation technique, some cannery sites have been operating successfully for upwards of 25 years, and the system has the potential for becoming very popular. Both spray and surface irrigation methods are used to apply the wastewater, therefore, the same pretreatment requirements apply, as outlined in Slide 42. Effluents from overland flow have shown lower nitrogen, phosphurus, and suspended solids removal than from irrigation procedures. Additional treatment may be required and one obvious combination is with the system described next.

The final system for applying waste to the land is shown in Slide 43. This is the rapid infiltration and percolation system. This system is utilized mostly with conventionally treated effluents. Large amounts of

wastewater, up to 300 feet per year, are either sprayed or flooded over the infiltration basin which is made up of highly permeable soil. A resting period is then provided which allows biochemical and chemical reactions to occur. Slide 44 indicates a number of the various schedules for application. Slide 44 also indicates the removal of nitrogen and phosphorus for several of these systems. Notice the wide variations among the systems. With slight modification the removal efficiencies of a number of these systems could be improved. These modifications include an adjustment of the aerobic and anaerobic conditions for nitrogen conditions and additions of aluminum or iron oxide coated silicates for removal of phosphorus.

Slide 45 indicates pretreatment requirements for rapid infiltration-percolation systems. Notice that the systems are divided into two catagroies - those that receive less than five feet of effluent per week and those that receive more than five feet per week. Secondary treatment or its equivalent is recommended for those systems that receive the higher amount. Clogging of the soil surface by suspended solids, mainly organics, has been the predominant management problem which has generated this requirement.

Slide 46 indicates the effluent qualities expected from established conventional and advanced wastewater treatment processes. Since the environments of land application systems are not as readily controlled nor have they been monitored for as long a period of time, the treatment process efficiency and expected effluent qualities are estimated in this slide. These estimates, however, have all been confirmed in various land treatment systems.

Notice the BOD and phosphorus levels in the effluents from land application. It is not unusual to measure BOD at less than 5 mg/l and phosphorus equal to background groundwater concentrations of 0.05 mg/l. It should be emphasized that all expected removal efficiencies depend on proper operation and maintenance for any of the systems.

Comparing effluent qualities is not enough. Each decision that must be made with respect to waste treatment has an associated cost.

When designing and figuring the cost of a waste treatment facility, several assumptions are made some of which are indicated in Slide 47. These include the projected population, the peak hourly, daily and weekly flow of wastewater, and the industrial growth in population equivalents of a municipality. These assumptions are used in the design of the facility and the purchase of the various equipment and units for the facility. Slide 48 indicates the

consequences of some of these assumptions for a conventioanl facility. The current population for our example is 10,000 people. The projected or design population is 25,000. The whole system is designed for the 25,000 people because of the expense of expanding and building onto a conventional treatment system. Because many of the units in a conventional treatment plant depend upon a minimum contact time, they must be designed to effectively handle the maximum flow that will assure that minimum contact time. This fact can multiply the design flow by a factor of two to two and one-half for a medium sized plant like the one exemplified in the slide. Units that would have to consider this daily variation in flow include all sedimentation units and most biological treatment units. Since these units would be in the facility and on line, the operating and maintenance costs would be for the design population, except for items like chemicals that are used on a unit volume treated basis.

The same assumptions would have to be made for a land application system. The consequences of those assumptions would be less drastic, however, as is indicated in Slide 49. It would be wise to purchase or hold firm options on the land necessary to treat the waste from the future design population. The actual land application system, however, can be easily expanded. It is unnecessary, therefore, to set it up for the design population. This would lower the initial construction and operating and maintenance costs, until the population expands. Also, since almost all land application systems have a storage factor included and since the options for application are so variable, less consideration has to be given to peak daily or weekly flows.

Slide 50 combines the last two slides for comparison purposes. Notice that not only construction costs are based on different population factors for the two types of systems but the operating and maintenance costs would be significantly different. These latter costs are the ones paid for wholly by the community.

There is a booklet that supplements this lesson and indicates several treatment options and their associated costs (Slide 51). Find the booklet titled, "Treatment Systems Comparisons". In general, the comparisons indicate that the cost of land application including secondary pretreatment are about the same as advanced waste treatment for the same design population. With only preliminary pretreatment, prior to land application, however, the effluent can still equal or better tertiary treatment and be more cost effective. The booklet is a very important part of the course so be sure to read it after you have turned off the recorder (Slide 52).

RETURN TO
LESSON PACKAGE

Booklet to Accompany the A-T

TREATMENT SYSTEMS, EFFLUENT
QUALITIES AND COSTS

Module 4
January, 1978

This booklet accompanies the audio-tutorial lesson titled Treatment Systems, Effluent Qualities and Costs. The intention of this booklet is to provide information in the form of tables and text concerning the various alternatives in waste treatment and the associated costs. You will be asked to determine the costs of four sample systems. We will use the costing information of Battelle (1974) and Van Note (1975).

The 11 liquid treatment strategies and the 12 sludge options investigated in the Battelle study are listed in Table 1. We will describe the most common liquid treatment strategies in the following discussion. These particular strategies were chosen because of their popularity prior to 1973, and it is expected they will continue to be used in the future. The liquid treatment strategies may be followed by any one of the 12 sludge options shown. However, in Figure 3 we have chosen sludge options No. 5 and No. 11 to use in this illustration.

The Battelle study compares the labor, energy requirements, and costs of the 11 treatment strategies as shown in Figure 3. Battelle also evaluates the removal of BOD, suspended solids, nitrogen, phosphorus, heavy metals, and the resultant sludge volume upon completion of treatment. This latter information on removal efficiencies is not included in this booklet but may be found by consulting the original study.

TABLE 1. Wastewater treatment strategies and sludge treatment options (Battelle study EQC 316, 1974)

Liquid treatment strategies

*1. Primary treatment with land application of liquid effluent
2a. Waste stabilization lagoon with surface water discharge
b. Waste stabilization lagoon with spray irrigation
3. Trickling filter with surface water discharge
*4. Trickling filter with land application
5. Activated sludge with surface water discharge
*6. Activated sludge with land application
7. Biological - chemical treatment
8. Activated sludge - coagulation - filtration
9. Tertiary treatment
10. Physical - chemical treatment
11. Extended aeration

Table 1 continued. . . .

Sludge treatment and disposal options

1. Sludge thickening, chemical conditioning, vacuum filtration, incineration, and landfill
2. Chemical conditioning, centrifuge dewatering, incineration, and landfill
3. Sludge thickening, conditioning by heat treatment, vacuum filtration, incineration, and landfill
4. Sludge thickening, digestion, sand drying beds, and landfill
5. Sludge thickening, digestion, and land spreading
6. Sludge thickening, digestion, and ocean dumping by pipeline
7. Sludge thickening, digestion, chemical conditioning, vacuum filtration, and landfill
8. Sludge thickening, digestion, chemical conditioning, vacuum filtration, and ocean dumping by barging
9. Chemical sludge thickening, vacuum filtration, incineration, and landfill of wasted residue
10. Chemical sludge thickening, vacuum filtration, recalcination and lime reuse, and landfill of wasted residue
11. Chemical sludge thickening, centrifuge dewatering, incineration and landfill
12. Chemical sludge thickening, centrifuge dewatering, recalcination and reuse, and landfill of wasted residue

*Land application of treated effluent

The first example consists of preliminary and primary treatment followed by land application of the effluent as illustrated in Figure 1.

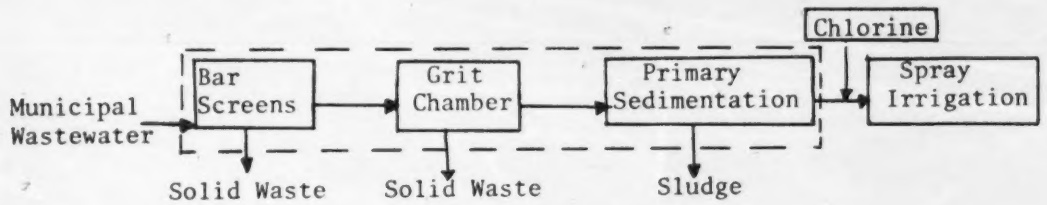

FIGURE 1. Primary treatment with land disposal of liquid effluent (Strategy 1 in Table 1)

Another common alternative presently adopted in many systems is the use of a waste stabilization pond followed by land application as shown in Figure 2. This system may be incorporated in areas where long term storage is required.

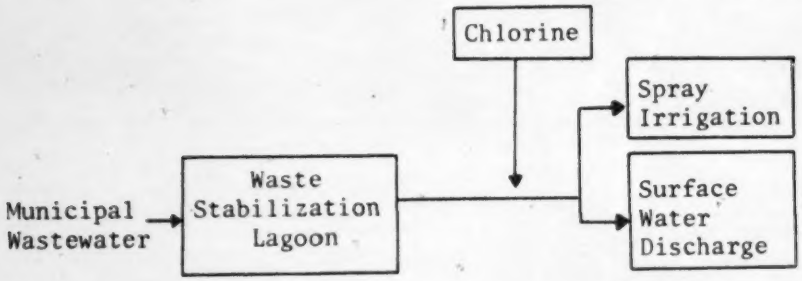

FIGURE 2. Waste stabilization lagoon (Strategy 2 in Table 2)

The third and fourth strategies listed in Table 1, consist of primary and trickling filter treatment followed by discharge to surface water or land application. Trickling filters are employed by a great many municipalities of all sizes.

The fifth and sixth strategies consist of primary and activated sludge treatment followed by discharge to surface water and land application, respectively. Activated sludge is presently the single most popular type of secondary treatment process being designed for municipalities. The complete mix activated sludge process was selected on its ability to consistently achieve high quality effluents. Furthermore, it is presently considered to be the superior method of biological treatment consistent with present and future treatment requirements as set forth in the Federal Water Pollution Control Act Amendments of 1972.

The seventh strategy consists of activated sludge treatment with alum addition and nitrification-denitrification followed by discharge to surface water. Land application of effluent water is not considered for this treatment sequence since nutrient removal would be superfluous if that mode of discharge were utilized. The nutrient removal capacity is presumably added to protect surface waters to which intended discharges are to be made. This facility probably is representative of the better technologies currently available for organics, nitrogen and phosphorus control for surface water discharge.

The eighth strategy consists of activated sludge treatment and coagulation-filtration followed by discharge to surface waters. Once again, land application was not considered as an ultimate disposal option since its use would preclude the necessity for the high level of treatment afforded by the addition of coagualtion-filtration.

The ninth strategy consists of coagulation-filtration and carbon adsorption followed by discharge to surface waters.

The eleventh strategy consists of extended aeration followed by surface water discharge of liquid effluents. Extended aeration can provide relatively high quality water if properly designed and hence effluents may be disinfected and released to surface water without further treatment. However, in practice extended aeration plants seldom perform to the theoretical capability of the process, hence their effluents should be considered for land application in the same manner as activated sludge effluents in the sixth strategy, above.

Costs are compared for the different treatment strategies. These include primary and secondary pretreatments prior to land application. The least cost sludge options were added to all of the treatment strategies to approximate the total cost of the waste treatment system. A comparison of these treatment and sludge handling costs is shown in Figure 3. These are average 1973 values selected from the Battelle study (Battelle, 1974) which gives a range of total operating and capital costs of up to $\pm$6¢/1000 gallons from the values in Figure 7 for some strategies.

Note that the cost of land application of primary and secondary pretreated effluents are approximately the same as Advanced Waste Treatment (AWT). The need for such a highly pretreated effluent prior to land application is questionable. In most cases, preliminary pretreatment prior to land application will result in an acceptable effluent quality, generally equal to or better than AWT. Preliminary treatment costs are estimated at 2.7, 0.84, and 0.4¢/1000 gallon for 1, 10, and 100 mgd plants respectively (Van Note, R.H., 1975). These costs did not include facilities such as offices, labs, pump stations, and outfalls. The dashed horizontal line "Land Application Costs" in Figure 3 represents an average cost for a land application system with pretreatment costs not included. This cost varies in the Battelle study from 21¢ to 31¢/1000 gallons. The variation in costs is due to the many factors which are site specific and could influence the cost of the land application system. Among these factors are land costs, distance to site, hydraulic loading rate of the soil, application system used, and climate. Preliminary treatments with land application have an average cost only slightly higher than are indicated by the dashed line. It can be seen from Figure 3 that land application is

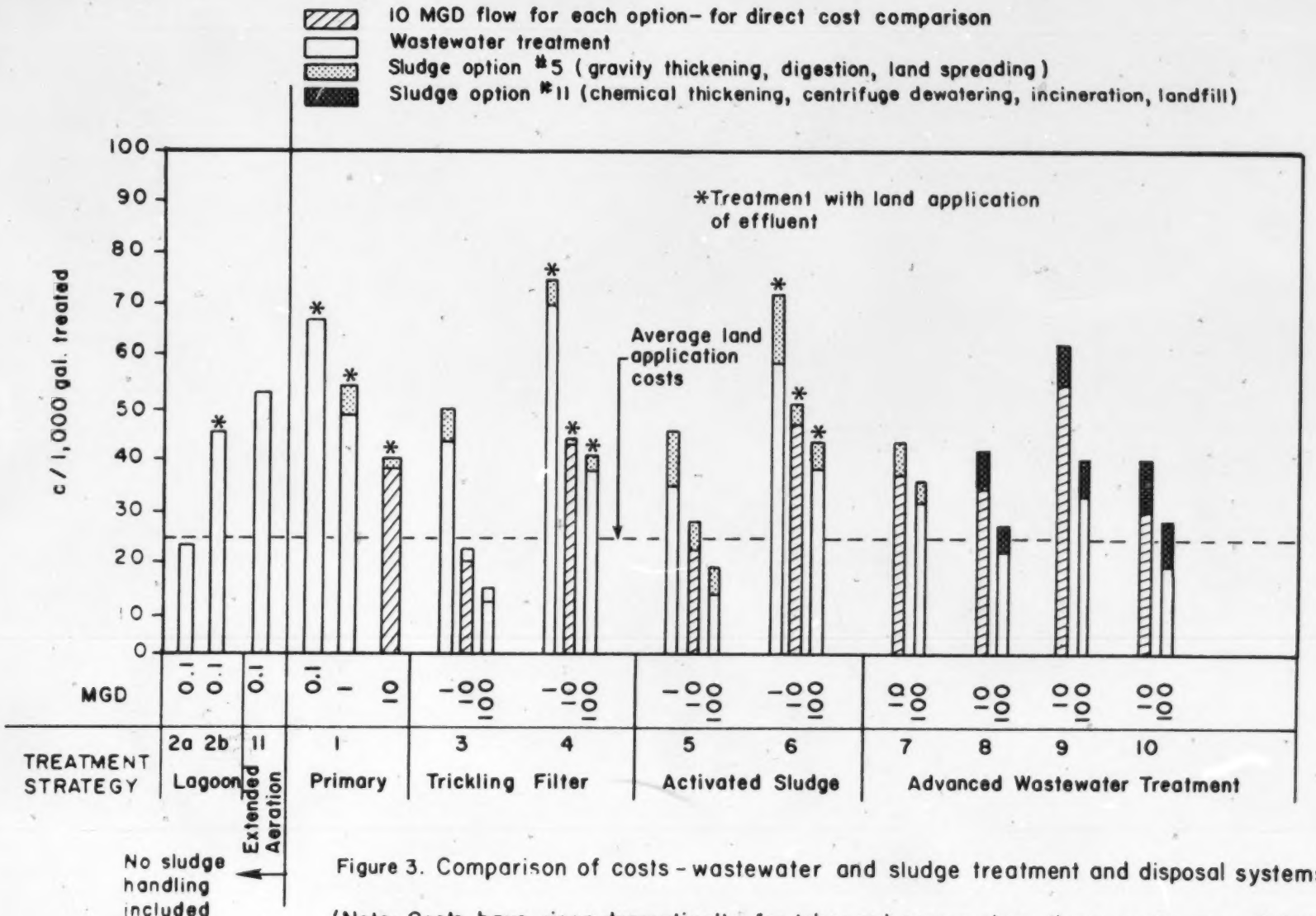

Figure 3. Comparison of costs - wastewater and sludge treatment and disposal systems

(Note: Costs have risen dramatically for labor and energy since these costs were determined.)

cost effective for small daily flows (.1, 1. 10 mgd) if only preliminary treatment of the wastewater prior to land application is used.

It must be remembered that the cost of obtaining an acceptable effluent varies significantly, depending upon the influent quality, the treatment process selected, and the receiving sink. The quality of effluent required to meet the 1977 goal for "best practicable technology" established by PL 92-500 is that of secondary treatment, i.e., 30 mg/1 BOD_5 and suspended solids where discharge is to navigable water. Land application systems must also meet groundwater quality requirements set by PL 93-523 "Safe Drinking Water Act", for inorganic and organic chemicals, and microbiological contaminants (Train, 1976).

Table 2 compares unit treatment process costs and expected effluent qualities. Many different wastewater treatment schemes can be assembled from this table. Preliminary estimated costs may be added up and the effluent qualities estimated.

Problems to Solve - (Solutions are found on pages 10 & 11 of this booklet)

#1. Compare the costs of conventional secondary treatment with the costs of land application. Use data from Table 2. Calculate the total cost in ¢/1000 gallon for preliminary treatment, pumping, primary sedimentation, activated sludge, sludge treatment, and disinfection for flows of 10 mgd and 1 mgd. Then calculate the total cost of preliminary treatment, transmission pumping and solid set irrigation. Compare the total costs. Now compare the effluent quality achieved by both systems.

#2. Compare the costs of conventional tertiary treatment with the costs of land application. Use data from Table 2. Calculate the total cost for preliminary treatment, pumping, primary sedimentation, activated sludge, anaerobic digestion of sludge, two-stage tertiary lime treatment, biological nitrification, biological denitrification, and disinfection for flows of 10 mgd and 1 mgd. Compare these costs with those calculated in problem #1 for land application. Compare the effluent qualities from each strategy.

When comparing the costs of conventional treatment with land treatment it is important to define what cents per gallon is referring to. In conventional wastewater treatment systems, the cost is based on cents per gallon of wastewater design flow. The cost for 1000 gallons of wastewater actually treated may be considerably higher than this value of deisgn flow. The cost of land application systems is based on cents per 1000 gallons of wastewater treated. If the land application system can be gradually expanded with increasing flows, the cost per 1000 gallons of treated wastewater could be lower than conventional treatment.

Table 2

Unit Treatment Processes - effluent qualities and costs
(after Van Note, R.H., 1975 except as noted)

	Estimated Effluent						¢/1000 gallons		
	BOD	TSS	TP	TKP	TN	pH	1 mgd	10 mgd	100 mgd
Untreated Wastewater	210	230	11	30	30	7.3			
Conventional Treatment									
Preliminary treatment - bar rack, grinding, grit chamber	210	230	11				2.7	.8	.4
Pumping - 30 ft TDH	210	230	11				6	2.6	1.3
Primary sedimentation - conventional (influent from preliminary treatment)	140	110	10				6.8	1.7	.8
Trickling filter - conventional (influent from primary sedimentation)	30	35	9				~13	4.8	3.5
Activated sludge - conventional (influent from primary sedimentation)	20	25	8				19	7	4
Sludge Treatment									
Anaerobic digestion (sludge influent from primary and secondary treatments) influent 5% S 70% VS effluent 4% S 54% VS							4.2	1.0	.57
Advanced Wastewater Treatment									
Filtration (from various flow schemes) Estimated influent	20	18	2.0						
effluent	10	5	1.0				11	5.5	2.5
Activated carbon - conventional (influent from filtration)	4	2	0.8				22	15	10
Two-stage tertiary lime treatment (influent from trickling filter, includes cost of dewatering sludge)	10	10	0.5	29	30		~22.5	7.8	3.4
Biological nitrification (influent from trickling filter)	10	15		1	30		11	4.6	2.9
Biological denitrification (influent from biological nitrification)	15	16		1	3		9.5	4.4	3.6
Ion exchange (influent from filtration)				<1	1		14	8.7	5.8
Ammonia stripping (influent from two stage tertiary lime treatment)				2	3		10	4.8	3.7
Disinfection (influent from any secondary or tertiary process, D.T. ≥ 15 min. ≤ 200 F.C./100 ml)							2.8	1.3	1.0

Land Application Systems*

Irrigation (2 in. per week, includes 20 wk. storage capacity)	4	5	1	5		
Surface					29	19
Spray - solid set					33	25
-center pivot					26	19
Overland flow (4 ipw)	17	18	4	2	22	14
Includes 10 wk storage						
Rapid Infiltration (12 ipw)	2	5	3	23	15	8
Includes 10 wk storage						
Transmission pumping (150 ft. head)					6	4

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*Pound, C.E., 1975

Note: Costs have risen dramatically for labor and energy since these values were computed in 1973 and in 1975.

Answers to Problems

#1. Secondary treatment

Process	Cost ¢/1000 gal 10 MGD	Cost ¢/1000 gal 1 MGD	Effluent Quality mg/l BOD	SS	TN	TP
Preliminary treatment	0.8	2.7				
Pumping	2.6	6.0				
Primary sedimentation	1.7	6.8				
Activated sludge	7.0	19.0				
Sludge treatment	1.0	4.2				
Disinfection	1.3	2.8				
TOTAL	14.4	41.5	20	25	30	8

Land application

	10 MGD	1 MGD	BOD	SS	TN	TP
Preliminary treatment	0.8	2.7				
Transmission piping	4.0	6.0				
Solid set irrigation	25.0	33.0				
TOTAL	29.8	41.7	4	5	5	1

A comparison of the total costs for each system shows a cost advantage for the conventional system. However, there is virtually no difference in costs between the two systems with a 1 mgd flow. Notice the difference in effluent quality between secondary treatment and land application.

Based on these figures, would you choose a conventional secondary treatment system or land application to handle a 10 mgd flow? Why?

#2. Tertiary treatment

Process	Cost ¢/1000 gal 10 MGD	1 MGD	Effluent Quality mg/l BOD	SS	TN	TP
Preliminary treatment	0.8	2.7				
Pumping	2.6	6.0				
Primary sedimentation	1.7	6.8				
Activated sludge	7.0	19.0				
Anaerobic digestion of sludge	1.0	4.2				
2-stage tertiary lime treatment	7.8	22.5				
Bio nitrification	4.6	11.0				
Bio denitrification	4.4	9.5				
Disinfection	1.3	2.8				
TOTAL	31.2	84.5	10	10	3	.5

Land Application

	10 MGD	1 MGD	BOD	SS	TN	TP
Preliminary treatment	0.8	2.7				
Transmission piping	4.0	6.0				
Solid set irrigation	25.0	33.0				
TOTAL	29.8*	41.7*	4	5	5	1

*Revenue from the harvest of cover crop not included

A comparison of the costs and resulting effluent qualities of the two strategies shows that land application is more cost effective than conventional tertiary treatment. Care should be taken when using general figures such as those used above because such costs are site specific. To arrive at an accurate cost for land application, it is critical to

know land costs, transmission mode, and distance of transporting waste, values which differ considerably from one site to another. The effluent qualities vary according to the way the site is managed. Notice how much the costs of land application and tertiary conventional treatment go down from 1 mgd to 10 mgd.

The difference in costs between land application and conventional tertiary treatment may be even greater because the above costs for land application include other items: cultivation of the crop, a network of monitoring wells, service roads, fencing, and administrative and laboratory facilities which are not included in the conventional treatment costs. The costs of land application shown here do not reflect how crop revenues may help offset the costs of operation and maintenance.